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Aliens in changing seascapes: a newly reported non-native sacoglossan (Mollusca, Heterobranchia) in the western Mediterranean Sea

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Abstract

We report the discovery of the Indo-Pacific sacoglossan *Elysia nealae* Ostergaard, 1955 from northeastern Sardinia (Central Tyrrhenian Sea). This is the first record of this species in the western Mediterranean Sea and only the second for the whole of the Mediterranean Sea following a report from Cape Epanomi, Greece. We discuss the identification of this species as well as the expansion of its geographical range. Data on the ecology and behavior of *E. nealae* leads us to hypothesize that the increase in the Mediterranean's water temperature due to climate change has favored this non-native species and contributed to its expanded distribution.

Keywords

Allochthonous species, climate change, *Elysia nealae*, Sardinia, sea warming, Tyrrhenian Sea

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Introduction

The marine biodiversity of the Mediterranean basin has a high rate of cryptic and endemic species, as revealed by several scientific works (e.g., Borsa 2002; Calvo et al. 2009; Claremont et al. 2011; Barco et al. 2013). With only 0.82% of the global oceanic surface, the Mediterranean Sea has more than 4% of all known marine species, with a rate of endemism estimated at 45% (Bianchi and Morri 2000; Coll et al. 2010; Mouillot et al. 2011; Costello et al. 2017). This is also true for marine molluscs, as demonstrated by recent systematic studies focused on Mediterranean molluscan diversity (Carmona et al. 2011; Prkíc et al. 2014; Furfaro et al. 2018b; 2021; Furfaro and Mariottini 2019; 2020; Martín-Hervás et al. 2020; Chimienti et al. 2020). In recent years, the introduction into the Mediterranean Sea of a large number of non-native species (Zenetos et al. 2004; Servello et al. 2019; Zenetos and Galanidi 2020; Trainito et al. 2021) has added elements to this already high biodiversity. The monitoring of the mollusc fauna in the Mediterranean Sea is essential to detect newly occurring and spreading non-native species and to investigate their control or management. Furthermore, the change in marine mollusc faunal composition

over time is a good indicator of environmental changes (Goddard et al. 2011, 2016, 2018; Nimbs et al. 2016; Eisenbarth et al. 2018; Furfaro et al. 2018a, 2020). Therefore, the study of alien species and their patterns of dispersal is crucial to implement proposals for conservation and environmental management.

Located in the center of the western Mediterranean Sea (central Tyrrhenian Sea, Italy), Sardinia is in a strategic position for the study and monitoring of alien species. In fact, it is in the middle of the temperature gradient that extends from the warm waters of the south to the colder waters of the northern Tyrrhenian Sea. Up to 2011, 11 alien marine molluscs were reported in the territory of Olbia, northeastern Sardinia (Doneddu 2011): eight belonging to the class Bivalvia [*Anadara transversa* (Say, 1822); *Arcuatula senhousia* (Benson, 1842); *Brachidontes pharaonis* (P. Fischer, 1870); *Ensis magnus* Schumacher, 1817; *Fulvia fragilis* (Forsskål in Niebuhr, 1775); *Magallana gigas* (Thunberg, 1793); *Ruditapes philippinarum* (A. Adams & Reeve, 1850), and *Xenostrobus securis* (Lamarck, 1819)] and three to the class Gastropoda [*Bursatella leachii* Blainville, 1817; *Melibe viridis* (Kelaart, 1858); *Rapana venosa* (Valenciennes, 1846)].

In 2015, an additional gastropod species, *Polycerella emertoni* Verrill, 1880, was added to the list of alien molluscan species known from this area of the Mediterranean (Trainito and Doneddu 2015). Here, we newly report *Elysia nealae* Ostergaard, 1955 (Heterobranchia, Sacoglossa, Plakobranchidae) from the western Mediterranean Sea, whose original distribution range is the northwestern Pacific Ocean.

Methods

During the last 10 years, we have conducted weekly periodical surveys from shore and in subtidal habitats by scuba diving along the coast of Olbia municipality and the Tavolara Punta Coda Cavallo Marine Protected Area (MPA) (Fig. 1C), collecting and documenting shells and

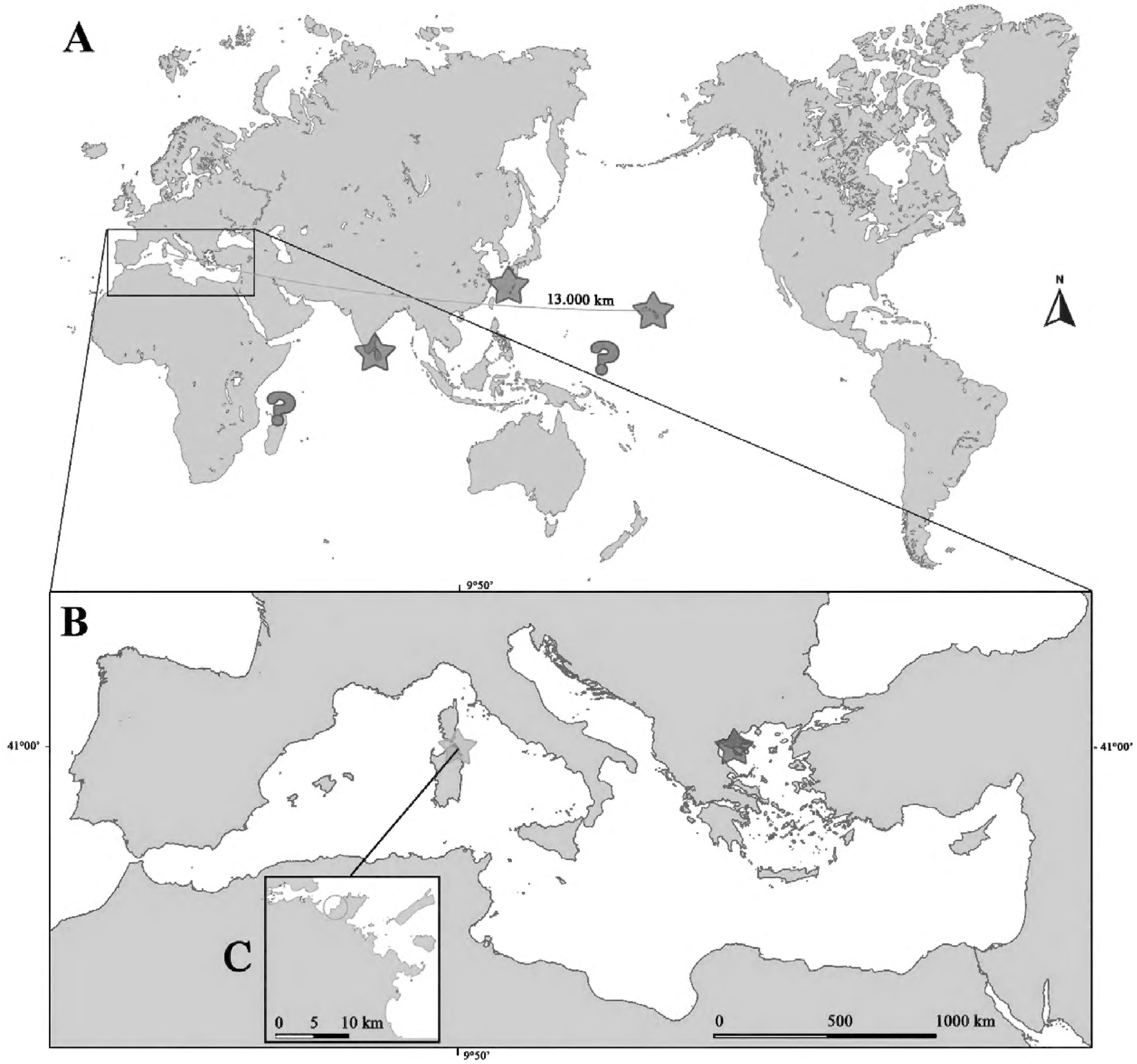

Figure 1. Map showing (**A**) Indo-Pacific records of *Elysia nealae* (blue stars = records from literature; blue question marks = uncertain records from websites), (**B**) Mediterranean records of *Elysia nealae* (red star = record in this study), and (**C**) study area in the northeastern Sardinia and, circled in red, the locality of the record reported here.

living animals. *In situ*, underwater photographs were taken with a mirrorless Sony A6000 camera in a Sea & Sea housing equipped with two Inon S2000 strobes. Photographs in the laboratory were taken with a Nikon D3X camera and dedicated strobe. Postproduction of photos was made using Photoshop CS 6 and Camera Raw for contrast, brightness, and the cropping of subjects. Two individuals of *Elysia nealae* Ostergaard, 1955 were collected, preserved in 96% ethanol, and deposited at the Department of Science, Roma Tre University (RM3), Rome, Italy. Data were collected as described by Chester et al (2019). The species was determined by external morphological investigation and a subsequent consultation of the original description, existing literature, and websites. Our tentative identification of the specimens as *E. nealae* was based on a global review of the external morphology of the currently 102 accepted species of *Elysia* Risso, 1818, two species considered as *inquirenda*, and three species considered as *nomina nuda* (MolluscaBase 2022). We compared the collected specimens to the original descriptions of all 107 species and to images of 102 of them in the scientific and grey literature (technical reports, books, websites, etc.), with cross checks to verify their reliability.

Results

Class Gastropoda
Subclass Heterobranchia
Superorder Sacoglossa
Family Plakobranchidae

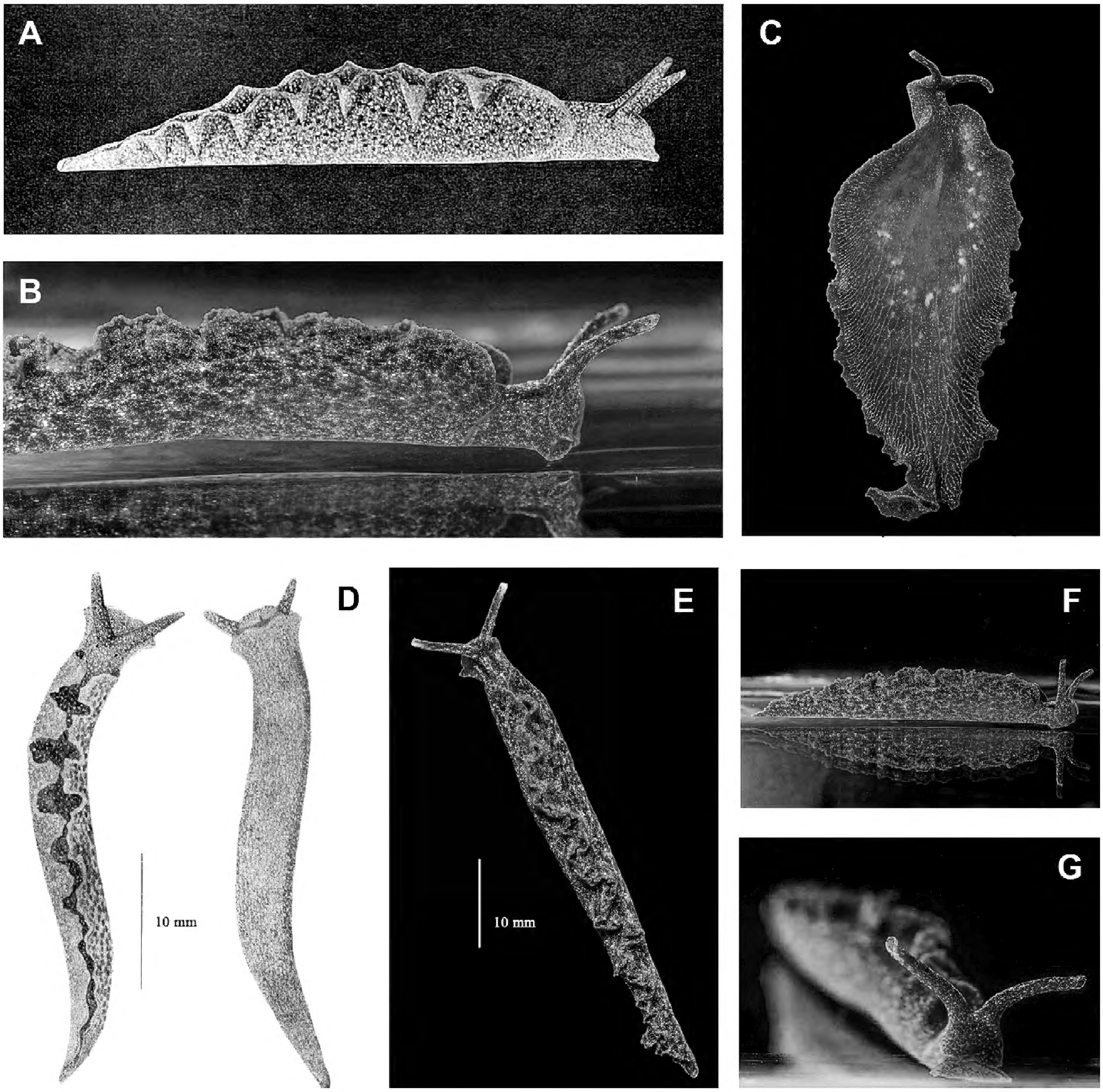

Figure 2. *Elysia nealae*. **A.** Original drawing (reproduced from Ostergaard 1955: pl. 1). **B.** Living Sardinian specimen. **C.** Dorsal view of a Sardinian specimen. **D.** Original drawing (reproduced from Ostergaard 1955: fig. 11) showing dorsal and ventral view. **E.** Living Sardinian specimen in dorsal view. **F.** Living Sardinian specimen in lateral view. **G.** Living Sardinian specimen in frontal view with rhinophores touching at the base.

Genus *Elysia* Risso, 1818

Elysia nealae **Ostergaard, 1955**
Figures 2, 3A–C

New records. ITALY – **Sardinia** • Olbia, Lu Carragioni; 40°54′06.1″N, 009°35′31.9″E; 2.5–3.0 m depth; 23.XI.2018; Egidio Trainito leg.; feeding and mating; visual census, hand-picked; 5 individuals observed, and 2 adults (50 mm long) collected (RM3_1825, RM3_1827).

Identification. *Elysia nealae* was described from a 33 mm long specimen found at Waikiki, Honolulu, O'ahu, Hawai'i, USA. The original description (Ostergaard 1955: 125) follows: "Body slender, elongate, tapering posteriorly. Parapodial lobes intensely folded, medially directed folds meeting dorsally. Rhinophores slender, straight, tapering toward extremities and directed anterolateral. Eyes prominent, placed at posterolateral bases of rhinophores, each surrounded by a small white area. Foot slightly bilobed with a shallow median notch anteriorly and tapered to an obtuse point posteriorly. Mouth located at median margin of head shield. Pale green throughout with small white specks and fine concentrated masses of green algae, particularly conspicuous on parapodial lobes. Margin of parapodial lobes and posterior tip of body greenish yellow.". The original description does not provide information on internal organs, and genetic data are not available in public databases. Our review of the external morphology of 107 existing species revealed

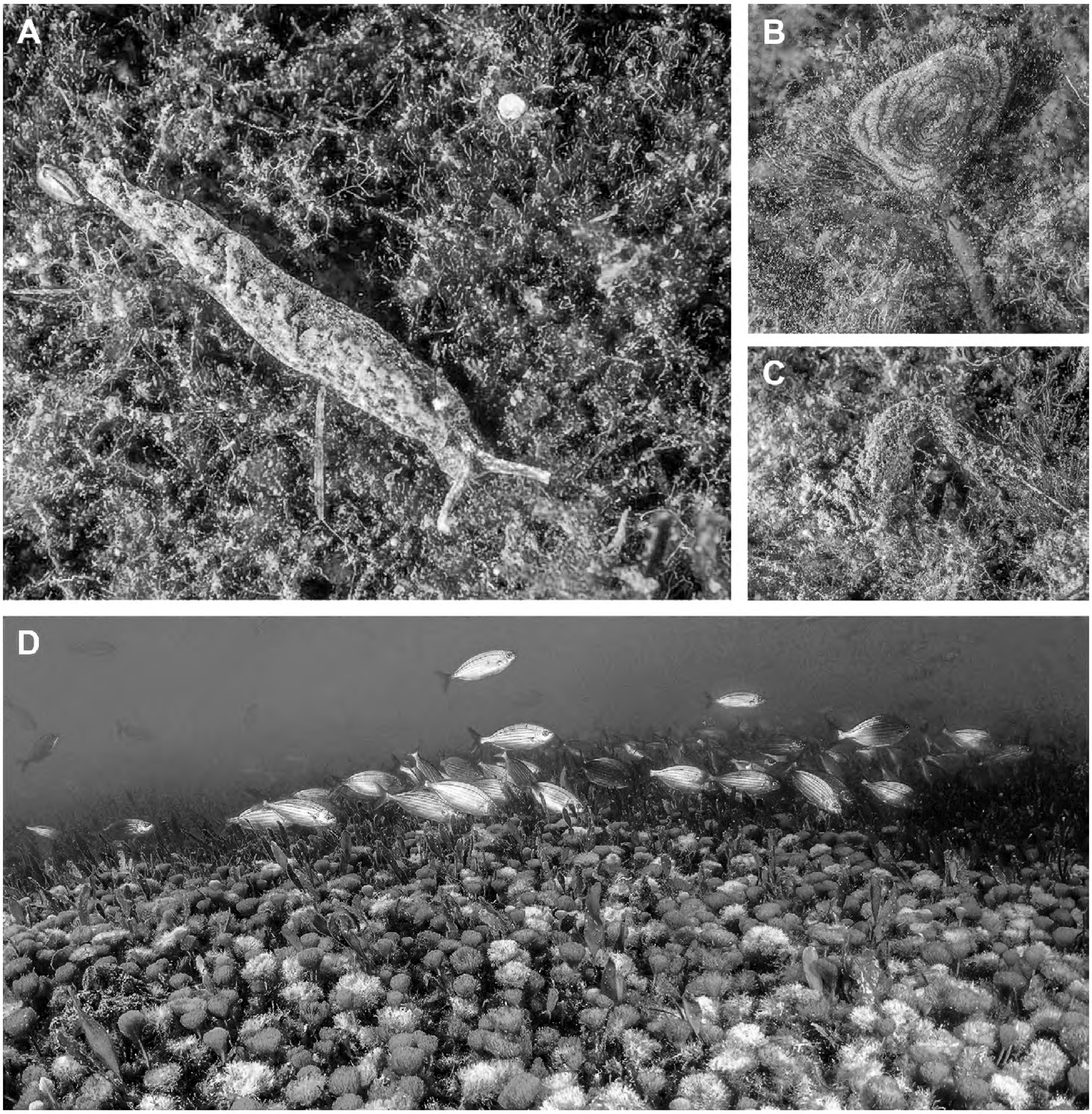

Figure 3. *Elysia nealae* in the changing seascapes in Lu Carragioni, Olbia, Sardinia (Tyrrhenian Sea) **A.** Living specimen (voucher specimen RM3_1825) photographed *in situ*. **B.** Coiled egg mass on the erect form of *Penicillus capitatus*. **C.** Animals burrowing in the sediment in response to light (voucher specimens RM3_1825 and RM3_1827). **D.** Wide view of one of the patches of *Penicillus capitatus* where *E. nealae* was found.

that the original description of *E. nealae* (Ostergaard 1955) perfectly matched the external morphology of the Sardinian specimens (Fig. 2A, B, D, E). Additionally, specimens of *E. nealae* photographed at the type locality closely match the specimens reported here (Gosliner et al. 2015; Pittman and Fiene 2021; C. Pittman pers. comm.).

Remarks. Other than the Hawaii Islands (O'ahu and Maui), records of this poorly known species come from Japan (Nakano et al. 2015) and India (Kumar et al. 2019) (Fig.1): additional records from Japan, Marshall Islands, Madagascar, and the Mayotte Archipelago are available online (https://en.seaslugword; http://www.underwaterkwaj.com; http://seaslugs.free.fr; all accessed on 2022-4-19), but the identifications are not always reliable. Manousis et al. (2020) reported the finding of a juvenile (~6 mm long) at Cape Epanomi, Greece (40°22′22.8″N, 022°53′16.2″E) at the depth of 0.5 m, but no information was given about the date of collection.

Discussion

The Sardinian specimens of *Elysia nealae* were found feeding, mating, and laying eggs on a shallow bottom (2.5–3.0 m) colonized mainly by *Caulerpa prolifera* (Forsskål) J.V. Lamouroux, *Cymodocea nodosa* (Ucria) Asch., and scattered, large patches of the thermophilic *Penicillus capitatus* Lamarck (Ulvophyceae, Bryopsidales, Udoteaceae)—both in the typical filamentous stage, the *espera* state, and in the consolidated summer phase in the form of an erect brush (Fig. 3D). Egg ribbons were found on the erect form (Fig. 3B), showing reproduction, and suggesting potentially stable populations. All observed individuals were adults more than 50 mm long, which is larger than any other species of sacoglossan known from the Mediterranean Sea. Some individuals burrowed into the sediment (Fig. 3C) in reaction to the strobes used while photographing them. This behavior is interesting and congruent with nocturnal habits of this species in its native range.

The finding of a reproductive population of *E. nealae* in Sardinia, along with the record from Greece (Fig. 1), is surprising due to the scarcity of knowledge on this species and, especially, the distance of these records to its native range (Hawai'i, Japan, Indonesia, and India, southwest to Madagascar). The most probable pathway of introduction may be via ballast water in ships, especially considering the heavy maritime traffic in the Gulf of Olbia, where cruise and cargo ships normally dock. We also hypothesize that the burrowing behavior that we observed may explain the rarity of sightings outside of the Hawaii archipelago where it is reported as relatively common. This species, therefore, may be much more widely distributed in the Mediterranean than currently known.

Our new Sardinian record of *E. nealae* confirms the importance of the Gulf of Olbia and surrounding areas of the central Tyrrhenian Sea as a key sentinel of a warming Mediterranean Sea and could serve as a strategic station to monitor changes in endemic Mediterranean fauna. The presence of *E. nealae* in the Mediterranean Sea confirm an increasing trend of invasion of the basin by non-native marine taxa, a process that could be accelerated by climate change (Bianchi et al. 2012). In the native range of *E. nealae*, it feeds on Udoteaceae, which agrees with the extensive patches of *Penicillus capitatus* observed by us. Until 2017, patches of *P. capitatus* were scattered and small, but in 2018 and in the subsequent years this alga had greatly expanded, which may be due to the recent increase in seawater temperature and the tropicalization of the marine biota (Sangil et al. 2010). The impact of climate change on Mediterranean marine biodiversity is well documented and has been referred to as the "tropicalization of the Mediterranean Sea" (Coll et al. 2010). Recently, this tropicalization was revealed to be even more dramatic on the warmest sectors of the Mediterranean Sea where it is leading to the collapse of native species (Albano et al. 2021). The warming sea facilitates the spread of alien species by reducing winter mortality, one of the main reasons for alien success (Amarasekare and Simon 2020), with the consequence that the new alien invaders profoundly alter ecosystem functions (Steger et al. 2021). From a seascape point of view (Fig. 3D), the mollusc reported here was found in an underwater seascape dominated by the rapid and recent expansion of the *Penicillus capitatus* (Fig. 3), unusual at these latitudes in the Mediterranean Sea. This makes the finding of an alien species less surprising and less out of context. In fact, it dramatically describes the high degree of change, whose direct impact is an impoverishment of indigenous biodiversity and of endemic habitats. The presence of *E. nealae* is strong confirmation that there are new characters at play in the long story of faunal change in the Mediterranean Sea, whose sequel is unknown and unpredictable.

Our record of *E. nealae* is the first of this species in the western Mediterranean Sea. Even though the external morphology leaves little doubt about our identification of the Sardinian animals as this species, an anatomical and molecular investigation of Mediterranean and native populations is advisable.

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Authors' Contributions

Conceptualization: ET, MD. Data curation: GF. Funding acquisition: GF. Investigation: ET. Methodology: ET,

MD. Supervision: GF. Validation: ET, GF, MD. Writing – original draft: ET, MD. Visualization: ET, GF. Writing – review and editing: GF, ET.

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